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Galaxy groups in the 2dF redshift survey: Effects of Environment on Star Formation

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ABSTRACT
We estimate the fraction of star forming galaxies in a catalogue of groups, constructed from the 2dF galaxy redshift survey by Merchán & Zandivarez. We use the η spectral type parameter of galaxies and subdivide the sample of galaxies in groups into four types depending on the values of the η parameter following Madgwick et al. We obtain a strong correlation between the relative fraction of galaxies with high star formation and the parent group virial mass. We find that even in the environment of groups with low virial mass $M \sim 10^{13}\ M_{\odot}$ the star formation of their member galaxies is significantly suppressed. The relation between the fraction of early-type galaxies and the group virial mass obeys a simple power law spanning over three orders of magnitude in virial mass. Our results show quantitatively the way that the presence of galaxies with high star formation rates is inhibited in massive galaxy systems.

Key words: galaxies: groups - physical properties - star formation rate

1 INTRODUCTION

Groups of galaxies are one of the most important laboratories in the universe to understand how this environment affects the galaxy formation. One of the main issues on the process of galaxy building is the rate at which they form stars. Several works has been devoted to study the star formation rate (hereafter SFR) in galaxies (Kennicutt 1983, Gallager, Bushouse & Hunter 1989, Kennicutt 1992, Gallagher & Gibson 1993, Kennicutt, Tamblyn & Congdom 1994, Gallego et al. 1995) and most of them agree that the luminosity of H_α provides a direct measure of the global photoionization rate, which can be used in turn to reliably estimate of SFR in massive ($M > 10 M_{\odot}$) stars.

Even when most of these studies have been carried out in galaxies, the extension to systems of galaxies is not very well understood yet given the impossibility to account with large samples suitable for statistical studies. The effects of environments on the global process of star formation in galaxy systems is a very important piece on the construction of theoretical models of galaxy formation and their consequent evolution. Some studies have claimed for a strong correlation between group early-type galaxy fraction and velocity dispersion. This could result from an increase in the early-type fraction and velocity dispersion as a group evolves, where galaxy morphologies change due to a mechanism such as mergers or from conditions at the time of galaxy formation (Zabludoff 1999). It is possible that mergers cause some evolution in the early-type fraction of poor groups and cease to be effective in richer groups and clusters.

Recently, Merchán & Zandivarez (2002) have constructed one of the largest sample of groups of galaxies until the present using a finding algorithm with the public 100K data release of the 2dF galaxy redshift survey ($\sim$ 100000 galaxies). The sample comprise 2209 galaxy groups inside the 2dF angular mask with redshifts in the range $0.003 \leq z \leq 0.25$. The group finding algorithm was designed modifying the traditional Huchra & Geller (1982) finder algorithm in order to take into account the 2dF magnitude limit and redshift completeness masks.

Madgwick et al. (2002) define a new parameter η in order to characterise the galaxy spectra on the 2dF galaxy redshift survey. This parameter is a linear combination of the first two projections derived from a Principal Component Analysis and their definition is such that its value correlates with the strength of absorption-emission features. A negative value of η is correlated with old stellar populations and strong absorption features whereas a positive value is related with young stellar population and strong emission lines. Figure 6 of Madgwick et al (2002) shows the strong correlation of the η parameter with the equivalent width of H_α in emission line galaxies. Consequently, η can be interpreted as a measure of the current star formation present in each galaxy.

In this work we use the η parameter to characterise the star formation rate of galaxy members of the group catalogue of the 2dF survey. We study the correlation of the

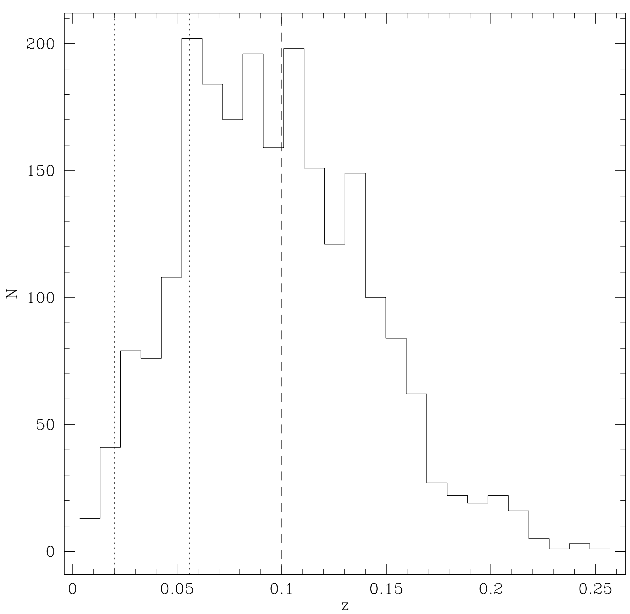

Figure 1. Redshift distribution of 2dFGGC groups. Vertical dotted lines are the boundaries of the volume-limited sample defined in section 3, and dashed line show the upper limit in redshift of our extended sample.

relative fraction of galaxies with different values of η and the group virial mass. The outline of this letter is as follows. In section 2 we describe the group catalogue and the statistical analysis performed is discussed in section 3. Finally, the main conclusions are given in section 4.

2 THE 2DF GALAXY GROUP CATALOGUE (2DFGGC)

Merchán & Zandivarez (2002) identify galaxy groups on the 2dF public 100K data release of galaxies with the best redshift estimates within the northern (NGP, $-37^{\circ}.5 \leq \delta \leq -22^{\circ}.5$, $21^h40^m \leq \alpha \leq 3^h30^m$) and southern ($-7^{\circ}.5 \leq \delta \leq 2^{\circ}.5$; $9^h50^m \leq \alpha \leq 14^h50^m$) strips of the catalogue. This sample comprise 84499 galaxies with final b_j magnitudes corrected for galactic extinction. The finder algorithm used on the identification is similar to that developed by Huchra & Geller (1982) but modified in order to take into account the sky coverage problems present on the current release of galaxies. The redshift completeness, which represent the ratio of the number of galaxies for which redshifts have been obtained to the total number of objects contained in the parent catalogue, and the magnitude limit mask, which correspond with variations of the parent survey magnitude limit with the position on the sky, are the two main sky coverage problems on this catalogue (see Figure 13 and 15 of Colless et al. 2001).

The 2dFGGC was constructed using the values $\delta\rho/\rho = 80$ and $V_0 = 200$ km s^{-1} which maximize the group accuracy (see section 4 of Merchán & Zandivarez 2002). The resulting groups catalogue comprises a total number of 2209 galaxy groups with at least 4 members and mean radial velocities in the range 900 km s^{-1} $\leq$ V $\leq$ 75000 km s^{-1}. The limit adopted in the number of members in galaxy groups is necessary in order to avoid pseudo-groups.

The virial group masses are estimated using the virial radius and the velocity dispersion ($M_{vir} = \sigma^2 R_V/G$, Limber & Mathews 1960) where the former is computed with the projected virial radius and the later with their radial counterpart. A robust estimation of this component is obtained applying the biweight estimator for groups with richness $N_{tot} \geq 15$ and the gapper estimator for poorer groups (Beers, Flynn and Gebhardt 1990, Girardi et al. 1993, Girardi and Giuricin 2000). These methods improve the velocity dispersion estimation in terms of efficiency and stability when dealing with small groups. Consequently, the catalogue has a mean velocity dispersion of 261 km s^{-1}, a mean virial mass of 8.5×10^{13} h^{-1} $M_{\odot}$ and a mean virial radius of 1.12 h^{-1}Mpc.

3 THE η SPECTRAL TYPE PARAMETER IN GROUPS

In this section the fraction of galaxies of different η spectral types in 2dFGGC groups is analysed as a function of group virial mass. The η parametrization of a galaxy spectral properties is defined by Madgwick et al (2002) for galaxies in the 100K data release of the 2dF galaxy redshift survey based upon a Principal Component Analysis of the galaxy spectra that takes into account the relative emission/absorption line strength present in a galaxy's optical spectrum. As shown in Madgwick et al (2002), the equivalent width of H_α emission-line, $EW(H_\alpha)$, is very tightly correlated to η for emission line galaxies. This classification correlates well with morphology and can be interpreted as a measure of the relative current star-formation present in each galaxy. The star formation rate for a galaxy is proportional to $EW(H_\alpha)$ times the galaxy luminosity. Consequently η can be used as a measure of a galaxy star formation rate relative to its luminosity.

We split the galaxies in the 2dFGGC groups into the 4 types of Madgwick et al (2002):

- Type 1: $\eta < -1.4$,
- Type 2: $-1.4 \leq \eta < 1.1$,
- Type 3: $1.1 \leq \eta < 3.5$,
- Type 4: $\eta \geq 3.5$.

This is not a criterion based upon morphology training set but rather by the shape of the η-distribution.

We have computed the fraction of galaxies of the different types as a function of group virial mass in two samples; The first one gives priority to galaxy completeness in order to avoid significant selection biases, the second sample is intended to incorporate as many groups as possible trying to avoid the incompleteness typical of a flux limited sample.

Our first sample of galaxies in groups, which is aimed to achieve the highest level of completeness, was selected taking into account the following prescriptions. Groups were limited to the redshift range $0.02 \leq z \leq 0.056$ (see Figure 1). This range was chosen due to the highly homogeneous distribution of group virial masses with redshift. Therefore, we prevent the possibility of a preferential bias to high mass groups in the sample. Secondly, we introduce a absolute

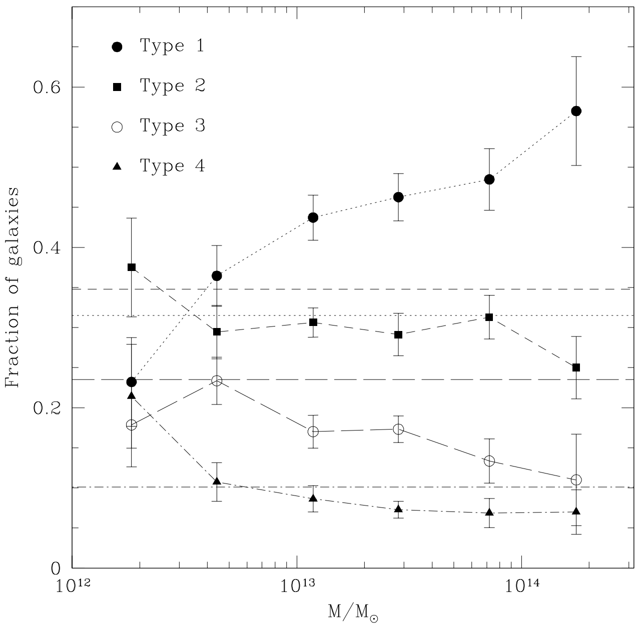

Figure 2. Fraction of the different spectral types as a function of group virial mass for our volume-limited sample. Error bars were estimated by the bootstrap resampling technique. Horizontal lines are the mean fraction of galaxies for different spectral types within the 2dF Galaxy Redshift Survey using the same selection criterion than the volume-limited sample. Dotted line correspond to Type 1 galaxies, short-dashed line to Type 2, long-dashed to Type 3 and dot-dashed to Type 4.

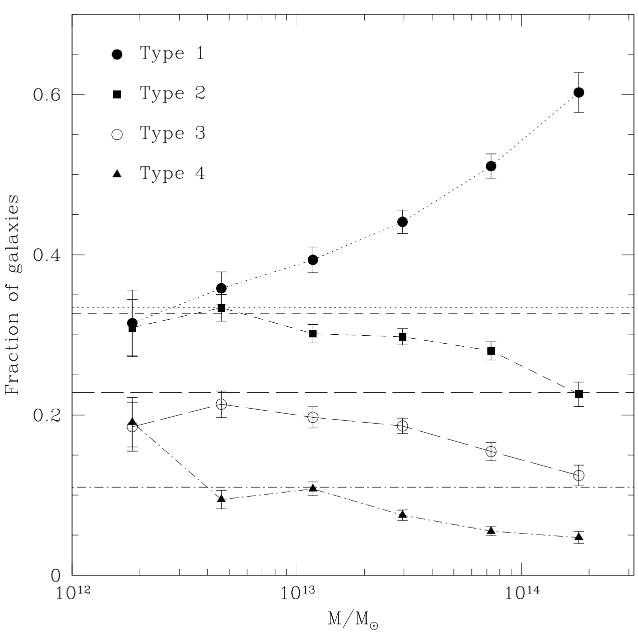

Figure 3. Fraction of the different spectral types as a function of group virial mass for our extended group sample. Error bars were estimated by the bootstrap resampling technique. Horizontal lines are the same as described in Figure 2 but using the current sample restrictions.

magnitude cut-off on the galaxies ($M_{b_J} \lesssim -17.2$) attempting a selection which is not biased to high luminosity galaxies, *i.e.* no spectral type preference. There are 1522 galaxies in 331 groups in this sample.

The second group sample considers a wider redshift range, $0.02 \leq z \leq 0.1$, and the galaxies in these groups have no absolute magnitude restriction, resulting in 7481 galaxies in 1155 groups. The large number of groups in this sample allow us to increase the reliability of our statistics, but we have not extended the redshift range beyond $z \sim 0.1$, since this could introduce strong biases in both, group selection and galaxy luminosities.

In Figure 2 we show the fraction of galaxies of each spectral type as a function of group virial mass for our volume-limited sample. We have binned group virial masses into six bins taking as abscissa the mean mass of the groups in each interval. Error bars in Figure 2 were estimated using the bootstrap resampling technique. We have also computed the fraction of galaxies of each type for all galaxies in the 2dF Galaxy Redshift Survey with the same selection criterion to determine a comparison level. It is clear that while the fraction of Type 1 galaxies show an increasing behavior with group virial mass, the fraction of galaxies with higher SFR ($\eta \gtrsim -1.4$) show the opposite trend. In particular, for Type 4 galaxies, which have the largest SFR, exists a variation of $\sim 75\%$ between the most massive and the less massive groups. This strong decrease of star forming galaxies on massive groups indicates the importance of environmental effects acting on galaxy systems.

There exists a significant difference between the fraction of galaxies of Type 1 (galaxies with very low SFR or early type galaxies) in most massive groups respect to that found when including field galaxies. If early-type galaxies are evolved merger remnants as expected in hierarchical models for galaxy formation, then the galaxy populations of more massive groups are more evolved on average. Allam et al. (1999) claim that the depressed star formation in galaxy groups is partly due to a relative over abundance of early-type galaxies and also to some mechanism that dampens star formation within late-type spirals. The later suggestion could also explain the observed decreasing fraction of star forming galaxies ($\eta \gtrsim -1.4$) with the virial group mass in our analysis.

The results of the second selected sample are shown in Figure 3. Even when this sample lacks of the level of confidence of the previous volume limited sample, we observe a very good agreement of the trends in both figures. The increase of the fraction of Type 1 galaxies in the least massive groups could be due to a possible lack of low luminosity galaxies in the sample. This effects could also explain the variations in the mean global fractions between Figure 2 and 3.

Regarding the contribution of each galaxy spectral type to the current SFR in groups, the influence of Type 1 galaxies is negligible since they are dominated by old stellar populations. Type 2 galaxies dominate in number over the remaining star forming types independently of group virial mass. However, since Type 3 galaxies have larger values of $EW(H_\alpha)$ and similar luminosities, their contribution to the SFR could be even higher than that of Type 2 galaxies. On the other hand, Type 4 corresponds to the tail of the η distribution (see figure 4 of Madwick et. al 2002) and is

dominated by particularly active galaxies such as starbursts and AGNs. Consequently special care should be taken when computing the contribution of these galaxies to the SFR, specially in low mass groups where the fraction of Type 4 galaxies is more important.

4 CONCLUSIONS

We have analysed the fraction of star forming galaxies in environments corresponding to groups and poor clusters of galaxies. The 2dFGGC is the largest sample available at the present and can be easily divided several times whilst still maintaining very reliable statistics. Our subsamples are the largest data sets used in the calculation of galaxy populations in groups so far.

The results of the analysis reported in this work clearly show a continuous trend of decreasing fraction of spectral types associated to star forming galaxies with group virial mass. Groups with virial mass $M \sim 2-4\times 10^{12}\ M_{\odot}$ have a relative fraction of galaxy spectral types similar to the global values. These results imply that even the environment of low mass systems $M \sim 10^{13}\ M_{\odot}$ is effective in diminishing the process of star formation in their member galaxies.

It is interest to note the way that the fraction of early-type galaxies (Type 1) increases monotonically with group virial mass which can be well fitted by a power-law of the form $\log(F_{Type1}) = 0.14\log(M/M_{\odot}) - 2.2$. This simple law provides a suitable fit to the fraction of Type 1 galaxies spanning over three orders of magnitude in group virial masses.

Our tests with two redshift restricted samples provide firm evidence of the lack of biases in our results that could arise due to the different galaxy luminosity functions of each spectral type as well as possible biased selection of high mass groups.

Recently Lewis et al. (2002) have studied a sample of seventeen known galaxy clusters using 2dFGRS spectra to compute SFR as function of local galaxy density and cluster-centric radius. They have found that the dependence of SFR on local density is independent of cluster velocity dispersion and presumably mass. It should be taken into account the different characteristics of the sample analysed in that paper and those analysed in this work. The sample study by Lewis et al. (2002) comprises more massive systems than the groups in our samples. A detailed analysis of the dependence of spectral types fractions on local galaxy density and group-centric distance for our samples, is given in Domínguez et al. (2002). They find that the more massive groups show a significant dependence of the fraction of low star forming galaxy on local galaxy density and group-centric radius whereas groups with lower masses show no significant trends. As we have discussed above, it is important to remark that our results and those obtained by Domínguez et al. (2002) refer to relative fractions of galaxy spectral types and not to current SFR in groups.

The present results could be very useful to provide constraints to the theoretical models of galaxy formation and evolution. In particular, the statistical behaviors reported in this work should be taken into account when considering the influence of environment on galaxy formation and evolution in semi-analytical models.

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